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# Reliability and validity of different methods of estimating the one-repetition maximum during the free-weight prone bench pull exercise

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**ABSTRACT**

This study examined the reliability and validity of three methods of estimating the one-repetition maximum (1RM) during the free-weight prone bench pull exercise. Twenty-six men (22 rowers and four weightlifters) performed an incremental loading test until reaching their 1RM, followed by a set of repetitions-to-failure. Eighteen participants were re-tested to conduct the reliability analysis. The 1RM was estimated through the lifts-to-failure equations proposed by Lombardi and O'Connor, general load-velocity (L-V) relationships proposed by Sánchez-Medina and Loturco and the individual L-V relationships modelled using four (multiple-point method) or only two loads (two-point method). The direct method provided the highest reliability (coefficient of variation [CV] = 2.45% and intraclass correlation coefficient [ICC] = 0.97), followed by the Lombardi's equation (CV = 3.44% and ICC = 0.94), and no meaningful differences were observed between the remaining methods (CV range = 4.95–6.89% and ICC range = 0.81–0.91). The lifts-to-failure equations overestimated the 1RM (3.43–4.08%), the general L-V relationship proposed by Sánchez-Medina underestimated the 1RM (−3.77%), and no significant differences were observed for the remaining prediction methods (−0.40–0.86%). The individual L-V relationship could be recommended as the most accurate method for predicting the 1RM during the free-weight prone bench pull exercise.

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**KEYWORDS**
Lift-to-failure equations; linear position transducer; load-velocity relationship; resistance training; velocity-based training

## Introduction

The one-repetition maximum (1RM) is commonly used in practice and scientific research for prescribing loads during resistance training sessions (Wood, Maddalozzo, & Harter, 2009). However, since the direct determination of the 1RM may not be feasible or practical at all time points throughout the training cycle, alternative methods that can accurately estimate maximal strength through less physically demanding testing may be of benefit. Previous research has proposed different equations to estimate 1RM strength using the maximum number of repetitions performed before reaching muscular failure (i.e., "*lifts-to-failure equations*") (Brzycki, 1993; Epley, 1985; Lander, 1984; Lombardi, 1989; Mayhew, Ball, Arnold, & Bowen, 1992; O'Connor, Simmons, & O'Shea, 1989; Wathan, 1994). Subsequently, contemporary methods that account for movement velocity at submaximal loads have received increased attention and have been proven to be a valid and reliable alternative for the prediction of exercise 1RM (González-Badillo, Marques, & Sánchez-Medina, 2011; Harris, Cronin, Taylor, Boris, & Sheppard, 2010; Jidovtseff, Harris, Crielaard, & Cronin, 2011).

The possibility of estimating the relative load (%1RM) through a "*general load-velocity (L-V) relationship*" was first examined by González-Badillo and Sánchez-Medina (2010). Following this seminal work, similar equations to estimate %1RM through general L-V relationships in other resistance training exercises (e.g., squat, vertical jump, leg press, bench pull, pull-ups, military press) have been proposed (Balsalobre-Fernández, García-Ramos, & Jiménez-Reyes, 2018; Balsalobre-Fernández, Marchante, Muñoz-López, & Jiménez, 2018; Loturco et al., 2018; Pérez-Castilla, García-Ramos, Padial, Morales-Artacho, & Feriche, 2018; Sánchez-Medina, González-Badillo, Pérez, & Pallarés, 2014). For example, two independent general L-V relationship equations during the prone bench pull exercise performed in a Smith machine (Sánchez-Medina et al., 2014) and with a free-weight barbell (Loturco et al., 2018) have been used to calculate 1RM. Sánchez-Medina et al. (2014) evaluated male junior and senior national-level athletes from four different sports (wrestling, canoeing, rowing or judo) and Loturco et al. (2018) evaluated male top-level athletes from two different sports (National Team rugby union players and professional mixed martial arts fighters). However, the general L-V relationships proposed by Sánchez-Medina et al. (2014) and Loturco et al. (2018) have not been cross-validated with other populations. Additionally, it is also important to determine

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whether a general L-V relationship obtained in a Smith machine could accurately predict the 1RM during its free-weight variant.

To mitigate issues regarding the general L-V relationship, recent research has suggested that the "*individual L-V relationship*" may provide more accurate estimation of an individual's 1RM (Banyard, Nosaka, Vernon, & Haff, 2018; García-Ramos et al., 2018; Helms et al., 2017; Hughes, Banyard, Dempsey, & Scott, 2018). One of the main limitations of the general L-V relationship is that the velocity associated with a submaximal relative load (%1RM) is subject-specific (Garcia-Ramos & Jaric, 2018; Pestaña-Melero et al., 2017). Therefore, due to the strong linearity of the individual L-V relationship, 1RM strength can be estimated by applying a linear regression model to velocity data collected under two (two-point method) or more (multiple-point method) submaximal loads (Banyard, Nosaka, & Haff, 2017; Banyard et al., 2018; García-Ramos et al., 2018; Hughes et al., 2018; Jidovtseff et al., 2011). It should also be noted that while the within-subject variability of the velocity associated with a submaximal load is lower than the between-subject variability, there are no meaningful differences for the velocity attained at the 1RM (V1RM) (Pestaña-Melero et al., 2017). Therefore, a standard V1RM can be used to estimate the 1RM through the individual L-V relationship (e.g., 0.17 m·s$^{-1}$ has been proposed for the bench press exercise) (García-Ramos et al., 2018). This reduces the need to create L-V profiles at 1RM loads for each individual.

The present study analysed the reliability and validity of three different 1RM prediction methods (i.e., lifts-to-failure equations; general L-V relationships; and individual L-V relationship) during the free-weight prone bench pull exercise. Specifically, the aims of this study were (I) to compare the reliability of the 1RM between the direct method and different prediction methods, and (II) to explore the concurrent validity of the three 1RM predictions methods. Based on previous results reported for the bench press (García-Ramos et al., 2018), we hypothesised that (I) the most reproducible 1RM value would be obtained through the direct method, and (II) the individual L-V relationship would provide the most accurate estimation of the 1RM.

## Methods

### Participants

Twenty-six men (22 rowers and four weightlifters) volunteered to participate in this study (mean ± standard deviation [SD]: age = 20.5± 2.9 years [range: 16–25 years]; body mass = 75.7 ± 9.3 kg; height = 1.76± 0.07 m; free-weight prone bench pull training experience = 6.1± 3.9 years). Participants were instructed to avoid any strenuous exercise during the 24 hours preceding each testing session. Participants were informed of the study procedures, and they or their legal guardians (for participants aged < 18 years) signed a written informed consent form prior to initiating the study. The study protocol adhered to the tenets of the Declaration of Helsinki and was approved by the Institutional Review Board.

### Design

A repeated-measures design was used to explore the accuracy of lifts-to-failure and velocity-based methods for estimating the 1RM during the free-weight prone bench pull exercise. Participants were asked to attend two testing sessions separated by 72–96 hours. The first testing session was used for validity analyses, while 18 participants returned for reliability analyses. Both testing sessions were identical and consisted of an incremental loading test until reaching the external load that could be completed for one repetition (1RM). Following 10 minutes of recovery, a single set to failure with a load that was 75–90% of 1RM was completed. All testing sessions were held between 15:00–19:00 hours.

### Equipment

The bench pull exercise was performed with a standard Olympic barbell and weight plates (Eleiko, Halmstad, Sweden). Participants lay down in a prone position with the chin in contact with the bench, elbows fully extended, and a prone grip of the barbell 2–3 cm wider than shoulder width. A repetition was not considered valid when the barbell did not touch the underside of the bench. The thickness of the bench was 8.5 cm. The legs were held by a researcher during all repetitions and the chin remained in contact with the bench. A linear velocity transducer (T-Force System; Ergotech, Murcia, Spain), which sampled the velocity of the barbell at a frequency of 1,000 Hz, was used to collect the MV of all repetitions. A very high validity and reliability of the T-Force System to monitor movement velocity has been reported elsewhere (Sánchez-Medina & González-Badillo, 2011).

### Testing procedure

A standardised warm-up (5 minutes of jogging, joint mobility exercises, and five repetitions of the free-weight prone bench pull exercise against 20 kg) was performed at the beginning of each testing session. The warm-up was followed by an incremental loading test starting with an unloaded Olympic barbell (20 kg). The external load was increased in 10 kg until the mean velocity (MV) of the barbell was lower than 0.80 ms$^{-1}$ (≈ 70% 1RM) and afterwards from 5 to 1 kg until the 1RM load was reached. Three repetitions were performed with light loads (MV > 1.10 m·s$^{-1}$), two with medium loads (1.10 m·s$^{-1}$ ≤ MV ≤ 0.80 m·s$^{-1}$) and one with heavy loads (MV < 0.80 m·s$^{-1}$). Intra-set rest between repetitions was 10 seconds and inter-set rest was 5 minutes. Participants received feedback of velocity immediately after each repetition and were encouraged to perform all repetitions at the maximal intended velocity.

An average of 9± 1 loads were lifted during the incremental loading test. The closest load of the incremental loading test to a MV of 0.70 m·s$^{-1}$ (L4) was used to estimate the 1RM through the general L-V relationships. L4 and the three preceding loads (L3–L2–L1) or only L1 and L4 were considered for estimating the 1RM through the individual L-V relationship (multiple- and two-point method, respectively). The absolute

Table 1. Descriptive data of the four loads used to determine the load-velocity relationships (mean ± standard deviation).

| | Absolute load (kg) | Relative load (%1RM) | Mean velocity ($m \cdot s^{-1}$) |
|---|---|---|---|
| Load 1 | 44.6 ± 10.7 | 48.9 ± 6.4 | 1.06 ± 0.10 |
| Load 2 | 54.6 ± 10.7 | 60.2 ± 5.5 | 0.93 ± 0.07 |
| Load 3 | 64.4 ± 10.8 | 71.3 ± 4.8 | 0.80 ± 0.05 |
| Load 4 | 74.0 ± 10.8 | 82.2 ± 4.7 | 0.68 ± 0.04 |

1RM, one-repetition maximum.

(kg) and relative (%1RM) loads, and the MV associated with these four loads are depicted in Table 1.

A set of repetitions-to-failure with a load ranging between the 75%1RM and 90%1RM (83.4± 3.6%1RM) was performed 10 minutes after the assessment of the 1RM. Participants performed the concentric phase at the maximum intended velocity and the eccentric phase under control. A pause of one second with the barbell resting on the floor was allowed between the eccentric and concentric phases. An average of 10± 3 repetitions were performed during the sets of repetitions-to-failure. The repetitions-to-failure assessment ended when the barbell did not make contact with the underside of the bench during two consecutive repetitions. The last repetition in which the barbell made contact with the underside of the bench was considered for the application of the lifts-to-failure equations.

## *1RM prediction methods*

### *Lifts-to-failure equations*

The Lombardi (1989) (1RM = [load.[1]] · Nº reps) and O'Connor et al. (1989) (1RM = [0.025 · load · Nº reps] + load) equations were used to predict the 1RM from the load (kg) and the number of repetitions (Nº reps) completed. Although the 1RM was also estimated from other lifts-to-failure equations, only the 1RM estimated by the Lombardi and O'Connor equations were presented in the results section since the errors of the other prediction methods were larger: Brzycki (1993) = 11.5± 11.3 kg, Epley (1985) = 9.2± 6.6 kg, Lander (1984) = 11.6± 11.1 kg, Mayhew et al. (1992) = 7.6± 4.6 kg and Wathan (1994) = 10.1± 6.8 kg. The absolute errors of the Lombardi and O'Connor equations were 4.1± 3.1 kg and 4.7± 4.0 kg, respectively.

### *General load-velocity relationship*

The MV recorded against a heavy load (L4) was used to estimate the 1RM through the equations proposed by Sánchez-Medina et al. (2014) (%1RM $18.5797 \cdot MV^2 - 104.182 \cdot MV + 147.94$) and Loturco et al. (2018) (%1RM= $-73.452 \cdot MV + 132.74$). A cross-multiplication was applied to estimate the 1RM after calculating the %1RM represented by the lifted load: $1RM = \frac{Load(kg) \times 100}{\%1RM}$.

### *Individual load-velocity relationship*

The MV recorded against four loads (L1–L2–L3–L4; multiple-point method) and only two loads (LI–L4; two-point method) were modelled through a linear regression to assess the individual L-V relationships. The 1RM was estimated from the individual L-V relationships as the load (kg) associated with a MV of 0.48 $m \cdot s^{-1}$. Note that the V1RM in the present study was 0.48± 0.04 $m \cdot s^{-1}$.

## *Statistical analyses*

Descriptive data are presented as means and SD. The normal distribution of the data (Shapiro-Wilk test) and the assumption of homogeneity of variance (Levene's test) were confirmed ($P>$ 0.05). Reliability of the 1RM was assessed by the coefficient of variation (CV) and the intraclass correlation coefficient (ICC; model 3.1) with their respective 95% confidence intervals. Acceptable reliability was defined as a CV < 10% (Cormack, Newton, McGuigan, & Doyle, 2008). A one-way repeated measures ANOVA with Bonferroni post hoc corrections and the Cohen's *d* effect size (ES) were used to compare the 1RM value between the different methods. Bland-Altman plots were also used to quantify the systematic bias and 95% limits of agreement between the actual and estimated 1RMs. Heteroscedasticity of error was defined as a coefficient of determination ($r^2$) > 0.1. The association between the actual and estimated 1RMs was assessed by the Pearson's correlation coefficient (*r*). The following criteria was used to examine the strength of the correlations: trivial (< 0.1), small (0.1–0.3), moderate (0.3–0.5), high (0.5–0.7), very high (0.7–0.9), or practically perfect (> 0.9). Reliability assessments were performed by means of a custom spreadsheet (Hopkins, 2000), while other statistical analyses were performed using the software package SPSS (IBM SPSS version 22.0, Chicago, IL, USA). Alpha was set at 0.05.

# Results

All methods showed acceptable reliability for the 1RM (CV < 7% and ICC > 0.80; Table 2). However, the direct method provided the greatest reliability (CV= 2.45% and ICC= 0.97), followed by the Lombardi equation (CV= 3.44% and ICC= 0.94), while no meaningful differences were observed between the remaining prediction methods (CV range= 4.95–6.89% and ICC range= 0.81–0.91).

The ANOVA revealed significant differences in the 1RM value between the different methods (F= 9.54, $P$< 0.001). When compared to the direct method (actual 1RM= 90.3± 13.8 kg), the lifts-to-failure equations tended to overestimate the 1RM (Lombardi equation= 94.0± 13.9 [$P$< 0.001, ES= 0.27, %= 4.08%] and O'Connor et al. equation= 93.4± 14.2 kg [$P$= 0.147, ES= 0.22, % = 3.43%]), the general L-V relationship proposed by Sánchez-Medina et al. underestimated the 1RM (1RM= 86.9± 13.5 kg [$P$= 0.040, ES= −0.25, %= −3.77%]), and no significant differences were observed for the general L-V relationship proposed by Loturco et al. (1RM= 89.9± 14.0 kg [$P$= 1.000, ES= −0.03, %= −0.40%]) and for the individual L-V relationships modelled by the multiple- (1RM= 90.1± 14.3 kg [$P$= 1.000, ES= −0.02, % −0.27%]) and two-point methods (1RM= 91.1± 13.7 kg [$P$= 1.000, ES= 0.06, %= 0.86%]). No heteroscedasticity of the errors were observed for any prediction method with respect to the actual 1RM ($r^2$< 0.1) (Figure 1). Correlations between the actual and estimated 1RMs were practically perfect for all prediction methods (*r* range= 0.926–0.966) (Figure 2).

# Discussion

This study identified the most accurate and reliable method for predicting 1RM during the free-weight prone bench pull

Table 2. Reliability of the 1-repetition maximum (1RM) obtained from different methods during the free-weight prone bench pull exercise.

| Procedure | Method | Session 1 (kg) | Session 2 (kg) | P | ES | CV (95% CI) (%) | ICC (95% CI) |
|---|---|---|---|---|---|---|---|
| Maximal single lift | Direct | 89.8 ± 13.4 | 90.1 ± 12.1 | 0.766 | 0.02 | 2.45 (1.84, 3.67) | 0.97 (0.93, 0.99) |
| Lifts-to-failure | Lombardi | 93.5 ± 13.4 | 93.9 ± 12.0 | 0.712 | 0.03 | 3.44 (2.58, 5.15) | 0.94 (0.86, 0.98) |
| | O'Connor et al. | 92.3 ± 13.3 | 93.9 ± 12.0 | 0.355 | 0.13 | 5.41 (4.06, 8.11)*# | 0.86 (0.66, 0.94)* |
| General L-V relationship | Sánchez-Medina et al. | 86.3 ± 13.8 | 86.9 ± 12.9 | 0.684 | 0.04 | 4.96 (3.72, 7.44)* | 0.91 (0.77, 0.96)* |
| | Loturco et al. | 89.4 ± 14.2 | 89.9 ± 13.3 | 0.714 | 0.04 | 4.95 (3.71, 7.42)* | 0.91 (0.77, 0.96)* |
| Individual L-V relationship | Multiple-point | 90.0 ± 14.2 | 89.7 ± 13.4 | 0.867 | −0.02 | 5.19 (3.90, 7.79)* | 0.90 (0.75, 0.96)* |
| | Two-point | 90.5 ± 13.6 | 92.0 ± 14.0 | 0.475 | 0.11 | 6.89 (5.17, 10.33)*# | 0.81 (0.56, 0.93)*# |

*P*, *p*-value; ES, Cohen's *d* effect size ([Session 2 mean – Session 1 mean]/SDboth); CV, coefficient of variation; ICC, intraclass correlation coefficient; 95% CI, 95% confidence interval; L-V, load-velocity. Above (CV) or below (ICC) the 95% confidence interval observed from the direct method (*) and Lombardi's lifts-to-failure equation (#).

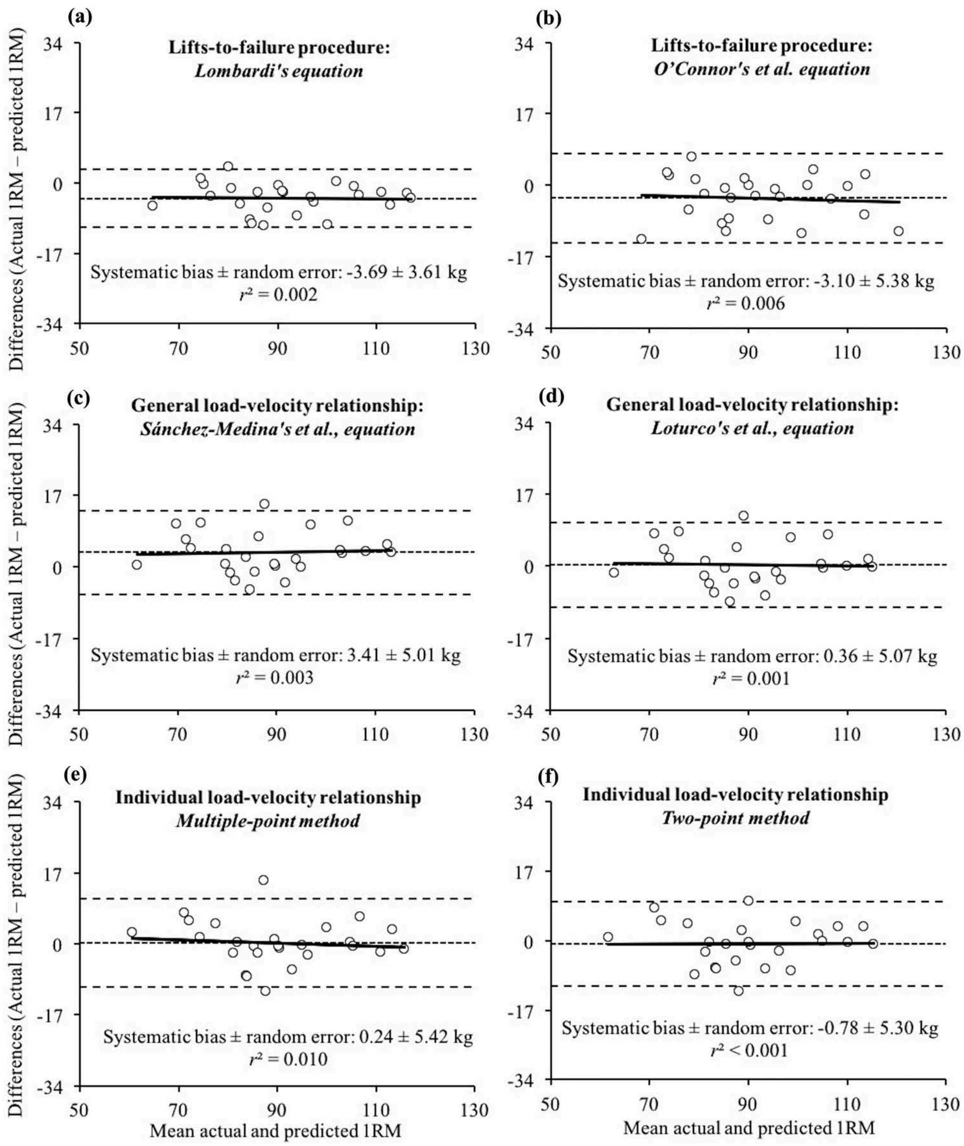


Figure 1. Bland-Altman plots showing the differences between the actual one-repetition maximum (1RM) and the 1RM predicted from the lifts-to-failure equations proposed by Lombardi (a) and O'Connor et al. (b), the general load-velocity relationship proposed by Sánchez-Medina et al. (c) and Loturco et al. (d), and the individual-load velocity relationship modelled through the multiple- (e) and two-point (f) methods. Each plot depicts the systematic bias and 95% limits of agreement (± 1.96 standard deviation; dashed lines), along with the regression line (solid line). The strength of the relationship ($r^2$) is depicted in each plot.

exercise. Our main finding revealed that only the general L-V relationship proposed by Loturco et al. (2018) and the individual L-V relationship modelled by both the multiple- and two-point methods did not systematically differ with respect to actual 1RM. The lifts-to-failure equations proposed by Lombardi (1989) and O'Connor et al. (1989) overestimated the 1RM, while the general L-V relationship proposed by Sánchez-Medina et al. (2014) underestimated the 1RM. The direct method provided the most reproducible 1RM value, followed by the Lombardi equation, while no meaningful

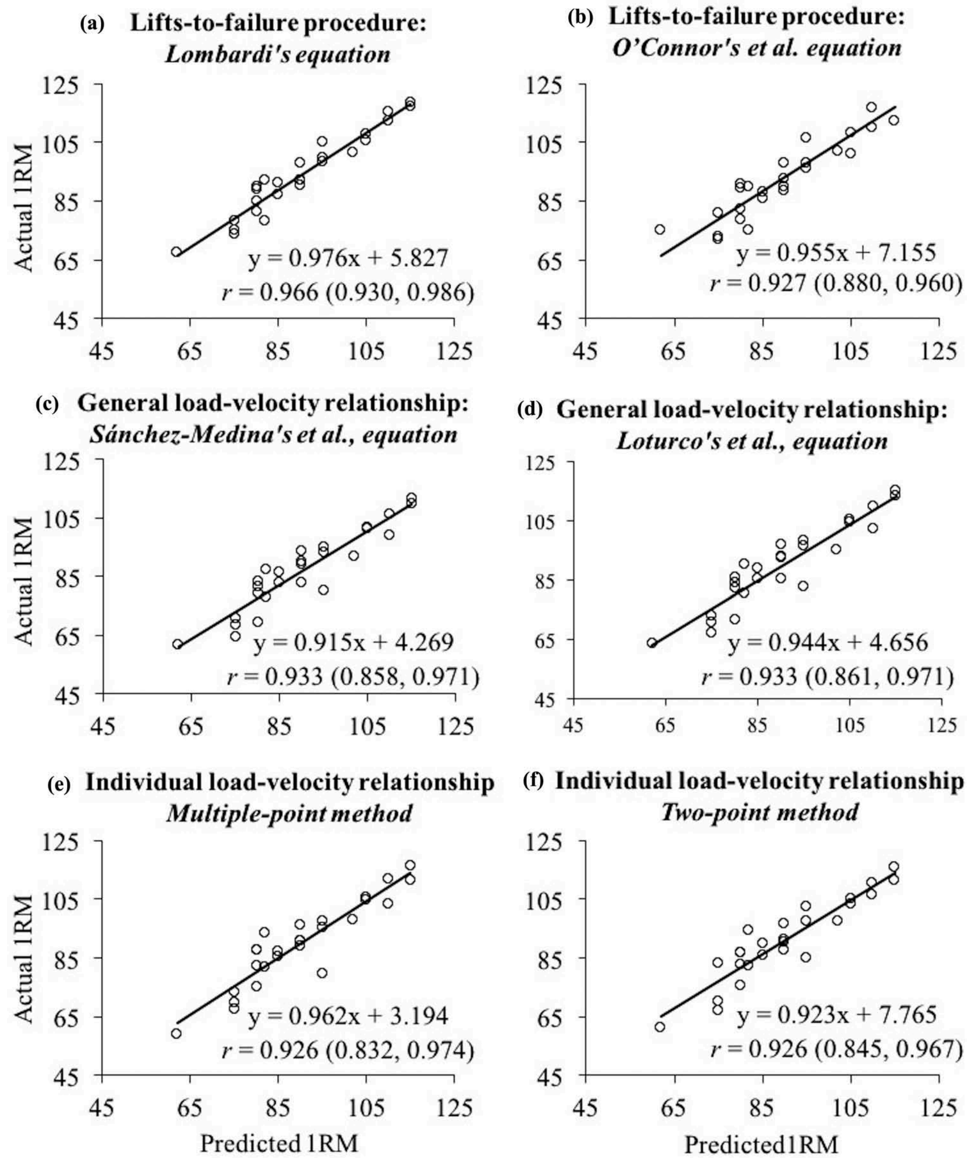


Figure 2. Association between the actual one-repetition maximum (1RM) and the 1RM predicted from the lifts-to-failure equations proposed by Lombardi (a) and O'Connor et al. (b), the general load-velocity relationship proposed by Sánchez-Medina et al. (c) and Loturco et al. (d), and the individual-load velocity relationship modelled through the multiple- (e) and two-point (f) methods. *r*, Pearson's correlation coefficient with 95% confidence interval.

differences in reliability were observed between the remaining 1RM prediction methods. All prediction methods provided a 1RM value that were practically perfectly correlated with the actual 1RM. Therefore, although the direct method should be recommended for obtaining a more reproducible 1RM value, it should be noted that all the prediction methods are able to estimate the free-weight prone bench pull 1RM with an acceptable level of reliability and validity.

The prone bench pull is a core exercise in many resistance training programs aiming to improve maximal power and strength of upper-body muscles (Baker & Newton, 2005). The direct determination of the 1RM is considered the gold standard test for evaluating maximal dynamic strength in non-laboratory situations (Wood et al., 2009). In line with the results reported for the bench press, squat and deadlift (Banyard et al., 2017; García-Ramos et al., 2018; Ruf, Chery, & Taylor, 2018), findings showed that the direct method demonstrated the greatest reliability. However, the reliability and validity of all prediction methods investigated within this study were satisfactory. Consequently, it is important that practitioners are aware of the pros and cons of the different 1RM prediction methods.

The primary advantage of lifts-to failure equations is that no sophisticated equipment is required to estimate 1RM. However, this prediction method may be impractical to implement on a daily basis and may interfere with training goals and adaptations. For example, a practitioner may be interested in determining the 1RM of one or several exercises before a training session to prescribe the external training load for that day. Completing warm-up sets followed by completing sets to failure for each exercise would be required for estimating 1RM strength. This procedure may not only be time consuming, but also induce fatigue that could impair performance during the rest of the training session (Párraga-Montilla et al., 2018; Richmond & Godard, 2004). Additionally, it should also be noted that the accuracy of the lifts-to failure equation is exercise-dependent (LeSuer, McCormick, Mayhew, Wasserstein, & Arnold, 1997; Wood et al., 2009). For example, Wood et al. (2009) revealed that the Mayhew, Epley and Wathan equations were the most accurate for estimating the 1RM during 10 resistance training exercises. Alternatively, LeSuer et al. (1997) recommended the Mayhew and Wathan equations for predicting the bench press 1RM, and the Wathan equation for predicting the squat 1RM. But, in the present study, we observed lower absolute errors for the prediction of the 1RM using the Lombardi (1989) and O'Connor et al. (1989) equations compared to other commonly used lift-to-failure equations (Brzycki, 1993; Epley, 1985; Lander, 1984; Mayhew et al., 1992; Wathan, 1994). Therefore, it is important to consider that although the equations provided by Lombardi and O'Connor et al. showed a comparable validity with respect to the velocity-based methods, the precision of these lifts-to-failure equations could be compromised in other resistance training exercises.

The general L-V relationship enables the estimation of the 1RM from the MV value recorded during a single repetition performed at the maximum possible velocity (González-Badillo & Sánchez-Medina, 2010). This procedure allows for daily estimation of the 1RM without inducing substantial levels of fatigue. However, it is important to consider that the general L-V relationship could also be associated with several limitations (Garcia-Ramos & Jaric, 2018). First, the MV associated with each %1RM is specific to the exercise being completed (e.g., bench press *vs*. bench pull) and execution of the movement (e.g., concentric-only *vs*. eccentric-concentric) (García-Ramos, Pestaña-Melero, Pérez-Castilla, Rojas, & Haff, 2018a; Pérez-Castilla et al., 2018; Sánchez-Medina et al., 2014-). Second, systematic differences in the velocity values recorded by different commercial devices have been reported (Balsalobre-Fernández et al., 2017; Fernandes et al., 2018; García-Ramos, Pérez-Castilla, & Martín, 2018). Therefore, it is important that the tested exercise closely replicates the conditions of the original study to ensure accuracy of the general L-V relationship. This recommendation is supported by the underestimation of the 1RM observed in this study using the equation proposed by Sánchez-Medina et al. who tested the prone bench pull in a Smith machine, while no systematic differences were observed using the equation of Loturco et al. who also used a free-weight barbell. Finally, it is important to note that the accuracy of the general L-V relationship is compromised when a light load is used for predicting the 1RM (García-Ramos et al., 2018). For example, in this study, the absolute error of the 1RM predicted from the MV recorded at L1 (≈ 50%1RM) was 14.7± 7.5 kg and 10.6 ± 7.8 kg for Sánchez-Medina et al. and Loturco et al. equations, respectively. This may be due to the increased between-subject variability of the velocity associated with light relative loads (Balsalobre-Fernández et al., 2018; Pestaña-Melero et al., 2017). Therefore, to obtain an accurate estimation of the 1RM through the general L-V relationship it is important to use a high relative load (> 85%1RM) and replicate, as closely as possible, the conditions of the study where the general L-V relationship was proposed.

To mitigate some of the limitations that occur with general L-V relationships (e.g., between-subject variations in velocity observed at certain %1RM), individual L-V relationships have been proposed (Banyard et al., 2018; García-Ramos et al., 2018; Helms et al., 2017; Jidovtseff et al., 2011). However, the biggest challenge associated with individualised L-V profiling is the selection of the V1RM used to predict the 1RM. Previous studies have used the individual V1RM (Banyard et al., 2017; Ruf et al., 2018) or mean V1RM for all participants (García-Ramos et al., 2018) to predict the 1RM. But, due to the low reliability of the V1RM (Banyard et al., 2017; García-Ramos, Pestaña-Melero, Pérez-Castilla, Rojas, & Haff, 2018b; Ruf et al., 2018) and the trivial differences between the between- and within-subject variability for the V1RM (Pestaña-Melero et al., 2017), we decided to use a standard V1RM of 0.48 $m \cdot s^{-1}$ for all participants. This procedure demonstrated a high level of validity for both the multiple- and two-point methods. This is practically important as the use of a standard V1RM can simplify the testing procedure due to the individual not being required to perform a maximal lift at any time point. However, it should be noted that due to systematic differences in velocities recorded by commercially used devices (Balsalobre-Fernández et al., 2017; Fernandes et al., 2018; García-Ramos et al., 2018), practitioners are required to know the average V1RM with the measurement device that they are using.

While it has been demonstrated that all prediction methods detailed in the current study can accurately and reliably predict 1RM in the free-weight bench pull exercise, future research is still required. The accuracy of general lifts-to-failure equations and L-V relationships are exercise dependent. Different lifts-to-failure equations have been recommended to maximise the accuracy in the prediction of the 1RM in other exercises (LeSuer et al., 1997; Wood et al., 2009). The L-V relationship also seems to provide a more accurate estimation of the 1RM during the bench press exercise compared to the squat and deadlift exercises (Balsalobre-Fernandez, Munoz-Lopez, Marchante, & Garcia-Ramos, 2018; Banyard et al., 2017; García-Ramos et al., 2018; Ruf et al., 2018). Additionally, while participants within the current study were all well-trained males, previous research has suggested that individuals with little to no resistance training experience may have highly variable 1RM strength levels (Ritti-Dias, Avelar, Salvador, & Cyrino, 2011). The L-V relationship also seems to differ between men and women (Balsalobre-Fernández et al., 2018; Iglesias-Soler, Mayo, Rial-Vazquez, & Haff, 2018; Torrejon, Balsalobre-Fernandez, Haff, & Garcia-Ramos, 2018). Therefore, future research should endeavour to identify the most accurate 1RM prediction method in different resistance training exercises and the possible influence of resistance training experience and sex.

## Conclusions

All 1RM prediction methods were able to accurately predict the 1RM during the free-weight prone bench pull exercise. However, we specifically recommend the individual L-V relationship over the lifts-to-failure and general L-V relationship equations. The determination of the individual L-V relationship is less time consuming and less prone to fatigue than the repetitions-to-failure procedure (especially if determined by the two-point method), while the accuracy of the general L-V relationship could be affected by slight variations of the testing procedure such as the use of a Smith machine or a different velocity measurement device. Finally, it should be acknowledged that the direct assessment of the 1RM demonstrates the greatest between-day reliability.


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## Disclosure statement

No potential conflict of interest was reported by the authors.


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